This invention relates to a method and apparatus for the separation and recovery of one constituent from another constituent in a comminuted mixture of such constituents. More particularly, it relates to a method and apparatus for the separation and recovery of values from comminuted ores, and more particularly by a flotation technique.

It is now well-known that a large number of values in ores may be separated from the gangue etc. by a flotation technique. These conventional separation procedures have suffered numbrous disadvantages including low efficiency, the need for a bank of units to carry out consecutive batch operations and considerable maintenance requirements.

One feature of the present invention is the provision of an apparatus for the continuous countercurrent separation and recovery of one constituent from a comminuted mixture containing such constituent and other constituents.

Another feature of the present invention is the provision of an apparatus for the continuous countercurrent separation and recovery of valves from a comminuted ore wherein the values are recovered at the upper portion of the apparatus and the gangue and waste material is recovered at the lower portion of the apparatus.

Yet another feature of the present invention is the provision

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an apparatus for the continuous countercurrent separation and recovery of values from a comminuted ore wherein the values are recovered at the lower portion of the apparatus and the gangue and waste material is recovered at the upper portion of the apparatus.

Still another feature of the present invention is the provision of a continuous method for the countercurrent separation and recovery of one constituent from a comminuted mixture containing such constituent and other constituents in a vertically upright restricted zone.

Another feature of this invention is the provision of a continuous method for the countercurrent separation and recovery of values from a comminuted ore in a vertically upright restricted zone, wherein the values are flotated-off from an upper region of said zone, the gangue and residue is recovered from a lower region of said zone and wherein the ore being separated is fed to an intermediate region of said zone.

Yet another feature of this invention is the provision of a continuous method for the countercurrent separation and recovery of values from a comminuted ore for a vertically upright zone wherein the gangue and residue are flotated-off from an upper region of said zone, the values are recovered from a lower region of said zone and wherein the ore being separated is fed to an intermediate region of said zone.

A further feature of this invention is the provision of an improved method for the froth flotation separation of values from gangue in a comminuted ore wherein there is enhanced recovery coupled

with enhanced grade.

The term "recovery" as used herein is intended to mean the ratio of solid material recovered to the solid material in the feed.

The term "grade" is intended to mean the ratio of the desired material in the material recovered to the total material recovered.

The present invention is operative in the froth flotation of any ore which has successfully been separated into value and gangue by froth flotation in the past. Non-limiting examples of suitable ores include:

1) Sulphides, for example cinnabar, cobaltite, smaltite, erythrite, chalcocite, covellite, chalcopyrite, bornite, galena, pyrite, marcasite, pyrrhatite, arsenopyrite, linneite, molybdenite, realgar, argentite and sphalerite;

2) Native metals, for example, gold, silver, copper and bismuth;

3) oxides, for example, bauxite, cassiterite, chromite, cuprite, ilmenite, hematite, specularite, manganosite, molybdite, rutile, alunite, anglesite and cerrisite;

4) non-silicate minerals of alkali and alkaline earth metals, for example, barite, calcite, celestite, cryolite, dolomite, fluorospar, magnesite, strontianate, halite and sylvite;

5) silicates, for example, andalusite, brucite, olivine,

krynite, mica, quartz and spodumene;

and 6) inert minerals, for example coal and graphite.

These above, and other ores may be flotated according to the present invention through the use of the conventional regulators, depressants, activators, principal promoters, frothers, promoter-assisting agents and selectivity-assisting agents well-known to those skilled in the art and selected for each of the desired ore. Conventional promoters or collectors, those reagents which provide ores to be floated with a water repellant surface that will adhere to air bubbles, include anionic agents, for example thé xanthates, the dithiosphosphates and the fatty acids and the cationic agents such as the fatty amine acetates. Non-limiting examples of such conventional promotors include:

1) Anionic agents, for example, xanthates for example, lauryl or octyl xanthates or a xanthate and Pb-Thallium group reaction product, thiophosphates, mercaptans, thioalcohols, thiocarbonalides, mercapto-benzothiazoles and organic sulphides, for example dixanthogens and thiuram disulphides;

2) carboxylic agents, for example fatty acids, for example aleric acid, tall oil, lalloel soap, naphthenic acid, black liquor soaps and cottonseed oil foots;

3) sulphoxy agents for example, turkey red oil, and higher alcohol sulphates, for example cetyl sulphate;

4) cationic agents, for example, amines, alkylalamines, α-naphthylamines, onium salts, isoureas and aldoximes;

and 5) fuel oil and kerosene.

Non-limiting examples of suitable regulators include sodium silicate, sodium hydroxide, sodium carbonate, polyphosphates, hydrogen fluoride, sulphuric acid, saturated brines and lime. Non-limiting examples of suitable depressants include excess sodium silicate, caustic starch, hydrogen fluoride, lactic acid, aluminum chloride, ferric chloride, sulphuric acid, starch, sodium, hydroxide, quebracho, dichromate, lime, bismith nitrate, tannin, barium chloride, alum, bleaching powder, citric acid, gelatin, dextrine, and glue. Non-limiting examples of suitable acitvators include barium salts, lead salts, for example barium chloride and lead nitrate, phosphomolybdic acid, phosphotungstic acid, barium sulphide, copper sulphate, hydrogen fluoride, sodium sulphide, and ferric chloride.

Non-limiting examples of suitable frothers include cresylic acid, pine oil, aniline, xylidine, pyridine and eucalyptus oil. Non-limiting examples of suitable promoter-assisting agents include kerosene,

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of the present invention, resulting in a recovery of 94.3% Fe.

Example 4

Bulk and Selective Flotation of Molybdite

The column and the process of the present invention were used to effect bulk flotation and a selective flotation of molybdite. The detailed operating conditions and test results for Run No. 4, a bulk flotation and Run No. 5, a selective flotation are given below

Run No. 4 Bulk Flotation (Mo and Bismuth)

Lower zone 10 ft. - 2"Dia
Upper zone 9 ft. - 2"Dia

REAGENTS 0.1#/ton Kerosene
0.1#/ton Pine Oil and Dowfroth 250 (1:1). (Dowfroth is the registered Trade Mark for a synthetic organic chemical used as an ore flotation frothing agent of the Dow Chemical Co.)
0.1#/ton Z-6 (Potassium AmylXanthate)

AIR 4.0 SCFM

Flowrate 1356 ml/min. Average

Solids 13% Average

TABLE 4

		ASSAY						Distribution	
	wt.	%Wt.	MoS_2	Bi	Cu	Fe	Insol	MoS_2	Bi
MoS_2	0.24	0.9	47.8	9.60	0.35	9.60	18.1	92.3	84.5
Tails	25.30	99.1	0.036	0.016	-	-	-	7.7	15.5
Feed	25.54	100.0	0.47	0.10	-	-	-	100.0	100.0

Run No. 5 Selective Flotation (Molybdenite Only)

Lower sone 10 ft. - 2"Dia
Upper sone 9 ft. - 2"Dia

REAGENTS 0.1#/ton Kerosone
0.1#/ton Pine Oil/Dowfroth 250(1:1)(Dowfroth is the registered Trade Mark for a synthetic organic chemical used as an ore flotation frothing agent of the Dow Chemical Co.)
0.2#/ton Sodium silicate

AIR 4.0 SCFM
Flowrate 1360 ml/min
Density 1.08
Solids 12 %

TABLE 5

	Assay								Distribution	
	Wt.	% Wt.	MoS_2	Bi	Cu	Fe	Pb	Insol.	MoS_2	Bi
MoS_2	0.12	0.5	79.4	6.56	0.26	0.71	0.01	13.9	90.0	28.9
Tails	25.10	99.5	0.044	0.081	-	-	-	-	10.0	71.1
Feed	25.22	100.0	0.44	0.11	-	-	-	-	100.0	100.0

The results of Runs No. 1-6 are summarized below in Table 6.

TABLE 6

Run No.	Float	Mo	Bi	Cu	Fe	Insol.	Recovery
1	Selective	44.2	7.25	0.11	8.15	32.0	80.9
2	Selective	48.9	3.85	0.21	2.70	38.9	92.0
3	Selective	54.6	12.10	0.38	3.15	17.0	94.4
4	Bulk	47.8	9.60	0.35	9.60	18.1	92.3 Mo 84.5 Bi
5	Selective	79.4	6.56	0.26	0.71	13.9	90.0
6	Selective	95.3	0.99				

The results of Tables 4, 5 and 6 indicate that the column and process of the present invention can separate MoS_2 and Bi from molybdite ore with a grade of about 95% and a recovery of 94 - 95%.

Example 5

Flotation of Copper from Copper Ore

Procedure

Five barrels of classifier overflow were utilized. Each barrel weighed 600 lb. at approximately 40% solids. The barrels were left to settle and the clear water was siphoned off.

The weight of solids used in every batch was determined by density measurement as shown in Experiment CP - 13 - 1.

Conditioning time with lime and R 208 (the sodium neutralized reaction product of diethyl and s-dibutyl phosphoric acids) was half an hour before adding Z6 (potassium amyl xanthate and frother.)

fuel oil, aniline, pyridene, ortholoIuidine, various detergents, pine tar oil, higher alcohol sulphates and creosotes. Non-limiting examples of suitable selectivity assisting agents include sodium silicate, citric acid, hydrogen fluoride, starch, dextrine, quebracho, gum arabic, polyphosphates, sulphuric acid, fluosilicates, dichromates, Palcaton, Palconate, various acids, alum, alkali resinates, sodium fluoride, caustic starch and guar gum.

It will, of course, be appreciated that the particular regulator, depressant activator, promoters, frothers, promotor-assisting agent and selectivity-assisting agent is selected according to the particular ore being treated. Thus, for example, to recover the mineral barite from an ore, a recommended regulator is either sodium carbonate or sodium silicate, a recommended depressant is either ferric chloride or aluminum chloride, a recommended activator is either a barium salt or a lead salt, a recommended promoter is oleic acid or a higher alcohol sulphate, a recommended frother is pine oil or cresylic acid, a recommended promoter-assisting agent is N-octadeoyl disodium sulphosuccinate and a recommended selectivity-assisting agent is either sodium silicate or citric acid.

The proportions of the various ingredients added to the ore is within the range well-known to those skilled in the froth-flotation art. Thus, the usual amount of promoters used is within the range of 0.01 - 0.2 lb/ton for the aryl dithiophosphoric acid type; 0.05-0.2 lb/ton for the xanthate type; 0.05 - 0.15 lb/ton for the thiocarbanilide type; 0.2 - 2.0 lb/ton for the fatty acid-type of vegetable origin; 0.1 - 0.5 lb/ton for the amine or amine salt type; 0.5 - 3.0 lb/ton for the anionic sulphonate-type; 0.2 - 2.0 lb/ton for the fatty acid or fatty acid soaps type; and 0.5 - 4.0 lb/ton for the kerosene or hydrocarbon type.

With respect to the various flotation modifying agents, the following proportions may be used:

1) Alkalies: lime, 0.5 - 5.0 lb/ton; soda ash or alkaline silicates, 0.5 - 3.0 lb/ton; sodium hydroxide, 0.5 - 4.0 lb/ton; and alkaline phosphates, 0.5 - 2.0 lb/ton;

2) Acids: sulphuric, 0.5 - 5.0 lb/ton; hydrofluoric and phosphoric, 0.5 - 4.0 lb/ton; and citric and tactic, 0.5 - 2.0 lb/ton;

3) Cyanogen compounds: alkaline cyanides, 0.01 - 0.5 lb/ton; and ferrocyanides and ferricyanides, 0.1 - 2.0 lb/ton;

4) Sulphites and sulphides: alkaline sulphites, 0.5 - 4.0 lb/ton; sulphur dioxide, 1.0 - 10.0 lb/ton; hydrogen sulphide, 0.2 - 2.0 lb/ton; alkaline sulphides, 0.5 - 5.0 lb/ton; and alkaline oxychlorides, 0.5 - 2.0 lb/ton;

5) Salts of metal ions; copper sulphate, chromic acid and dichromates, 0.2 - 5.0 lb/ton; mercuric nitrate, lead nitrate, lead acetate, aluminum sulphate, aluminum chloride, manganates and permanganates; 0.1 - 2.0 lb/ton; and ferrous sulphate and ferric sulphate 0.1 - 1.0 lb./ton;

and 6) Organic colloids; quebracho, tannic acid, Palcoton and Palconate, and glue, 0.1 - 0.5 lb/ton; synthetic organic depressants, 0.1 - 1.0 lb/ton; and starch, 0.1 - 1.0 lb/ton.

In the case of frothers, in conventional practice they are used to enhance and assist in the introduction of small air bubbles into the flotation pulp and the collection of the unbroken mineral-laden bubbles on the pulp surface. For this purpose frothers such as the synthetic higher alcohol type have heretofore been used in amounts of from 0.01 - 0.5 lb/ton; pine oil has been used in an amount of 0.03 - 0.2 lb/ton; while cresylic acid and encalyptus oil have been used in an amount of 0.05 - 0.2 lb/ton. However, in the present invention, the frother is

used to control the air bubble size. To achieve this end, the amount of frother which may be used is generally less than that used heretofore. The bubble size is controlled in this manner preferably to achieve optimum surface area of the bubbles per volume of the column

The rate of introduction of aqueous washing medium at the top of the vertically erect column, the rate of introduction of air at the bottom of the vertically erect column and the rate of introduction of feed slurry at a point between the top and the bottom of the vertically erect column are all interdependent.

Stated in its broadest terms, however, the column should be operated at its optimum capacity for a given ore while retaining a maximum recovery, but at conditions which do not approach "flooding" conditions. By "flooding" conditions is meant that the downward velocity of the material in the column is such that it decreases the velocity of the rising bubbles to such an extent that more bubbles are produced than can escape from the top of the column. This results in a "compacted bubble condition" which leads to a violent swirling action and explosive ebullition within the column, which severely hinders and may sometimes completely interfere with the separation.

Stated another way, moreover, the air pressure, which controls the rate of introduction of air at the bottom of the column, must be greater than the hydrostatic pressure on the means which provides the air bubbles i.e. the bubbles or diffuser. This expression may be expressed mathematically, as follows:

$$p = hd - k$$

where p is the pressure of air delivered to the bubbler or diffuser,

h is the height of the column,

d is the average density of the contents of the column

and k is a factor (which is greater than O but less than 7) which is a characteristic of the bubbler or diffuser.

A pressure of air of up to about 20 p.s.i.g. is usually used.

It is clear from the above formula and description that the amount of air passing through the column per unit time per unit area of cross-section of the column is a function of the slurry flow rate and the density of the slurry, the number of air bubbles, and the size of the air bubbles. The means to form the bubble of air may be any suitable perforated member. One type which has been found suitable is a conically shaped porous metal air diffuser, generally having perforations of a size 5 microns to 2500 microns with a size of 10 microns being particularly preferred. With perforations within this range, the bubble size would normally range from about 1000 to about 10,000 microns with a preferred size being about 1600 microns. Of course, as specified above, the frother is used to control the bubble size and so the bubble size can be maintained at a reasonable size even with larger perforations in the perforated member. A size of between 3000 microns and 6000

microns is permissible although other sizes are possible. Another type which has been found suitable is a cylinder having an elipsoidal cross-section, whose closed elipsoidal end is of porous metal having perforations of the sizes referred to hereinabove. Additionally porous metal plates having apertures of the sizes referred to hereinabove, porous ceramic plates having apertures of the sizes referred to hereinabove and other means such as punctured rubber, filter cloth, etc., with apertures of the sizes referred to hereinabove are suitable. Such means must be connected to a source of air under pressure which is separated from the interior of the column except through such porous means.

As in conventional practice, the ore is crushed, screened, ground and classified and formed into an aqueous slurry. In the present invention, however, the slurry is formed in an agitation conditioning tank ~~task~~, which contains means for intimately mixing the ground ore with the water and with the necessary conditioning and flotation agents. The slurry usually contains from about 5 to about 70% solids, but this is dependent upon the particular ore being slurried. The slurry from the agitation conditioning tank must be in pumpable form and is fed at such a rate that the slurry entering the column as feed contains more solids than are in the column at any particular instant of time. This may require changes in the flow rate and/or solids content of the slurry from time to time. The conditioning and flotation agents are added in conventional quantities to the slurry in the agitation conditioning tank, and the required amount of frother to control the bubble size is also added at this time.

The washing liquid entering at the upper portion of the column is an aqueous system. It usually is water, but for certain ores it may be a dilute aqueous solution of acids, etc. The rate of flow of such aqueous system is, as specified hereinabove, dependent upon the various parameters of the system. Generally speaking the rate of flow is such that it dilutes the slurry to prevent the unseparated slurry from rising.

By one broad aspect of this invention, there is provided a method for the separation of one constituent from another constituent in a comminuted mixture of those constituents, the method comprising, firstly, establishing and maintaining a downwardly flowing stream of aqueous medium within a vertically aligned, elongated zone; then establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of that zone; then establishing an aqueous slurry of that comminuted mixture and at least one conditioning agent which renders one of the constituents hydrophobic; then introducing that slurry into that zone at a region in the zone above the lower portion at such a rate that the solids content of the slurry is greater than the solids content in said zone; then collecting one constituent as overflow at the upper region of said zone; and finally collecting the other constituent as underflow at the lower region of said zone.

This method may be used to collect the values in the ore in the form of solid particles adhered to the air bubbles, with the gangue being carried out as underflow from the bottom of the column, or alternatively, may be used to collect the gangue in the form of solid particles adhered to the air bubbles and to collect and recover the values as underflow. Advantageously, the method is conducted by correlating the rate of input of water with the rate of input of slurry feed and the rate of underflow to maintain a substantially constant

upper level in the column. Also, the air bubbles may be produced by passing the air under pressure through a perforated member, the pressure being up to about 20 p.s.i.g., the size of perforations being about 5 to about 2500 microns, with the air bubbles having a size of about 1000 to about 10,000 microns. The slurry usually has a solids content of about 5-75%. The process is particularly suited for the separation of quartz as overflow from iron values as underflow, the separation of quartz and dolomite as overflow from iron values as underflow, dolomite and iron values as overflow from quartz as underflow, of molybdenum sulphide and bismuth as overflow from gangue as underflow, of molybdenum sulphide as overflow from gangue as underflow and copper values as overflow from gangue as underflow.

By yet another aspect of this invention, there is provided an apparatus comprising: a vertically elongated column; means for introducing aqueous medium at the upper portion of the column; means for introducing a feed slurry to an intermediate portion of the column; means for introducing air bubbles into the lower portion of the column; means for collecting one solid constituent of the slurry from the lower portion of the column; and means for collecting another solid constituent of said slurry from the upper portion of said column, the other constituent being in the form of solid particles adhered to the air bubbles.

The apparatus preferably includ. an upper zone, an intermediate zone and a lower zone. The water inlet means usually extends into the upper portion of the upper zone. The slurry feed inlet is to the intermediate zone. The bubbler is situated in the lower zone and at the lower portion of the lower zone there is provided outlet means for the underflow. Collecting means are provided at the upper portion of the upper zone. Preferably, means are included for the preparation of the feed slurry. A preferred feature of the invention is the reduction of the cross-sectional area of the upper zone by about 1/4 to 3/4 of the area of the other two zones, as by a reduction in its diameter or by insertion of an axial solid tube therein or an axial slurry feed line. In the latter case, the water inlet means may be concentric with the slurry feed line. The bubbler may be a conical member with fluted perforated walls, or an elliptical cylinder, the top of which is perforated, these vessels being connected to a source of air under pressure. In each case the perforations may be about 5 to about 2500 microns in size. In another embodiment the upper collecting means includes a top chamber to an inclined weir therein and an inclined outlet cooperating with the weir.

In the drawings,

Fig. 1 is a schematic view partly broken away, of one embodiment of apparatus according to this invention,

Fig. 2 is a vertical cross-section of the flotation column of Fig. 1,

Fig. 3 is a section along the line III - III of Fig. 2,

Fig. 4 is a section along the line IV - IV of Fig. 2,

Fig. 5 is a vertical cross-section of a top portion of a flotation column according to another aspect of this invention,

Fig. 6 is a vertical cross-section of a top portion of a flotation column according to another aspect of this invention

Fig. 7 is a vertical cross-section of a top portion of a flotation column according to yet another aspect of this invention

Fig. 8 is a vertical cross-section of a top portion of a flotation column according to still another aspect of this invention,

Fig. 9 is a vertical cross-section of a bottom portion of a flotation column according to a further aspect of this invention, and

Fig. 10 is a section along the line X - X of Fig. 9

Turning first to Fig. 1, the flotation column indicated generally at 10 comprises an upper section 11, an intermediate section 12 and a lower section 13. The cross-section of the flotation column may be circular, eliptical, square, rectangular or any other transverse section of a plain geometrical figure. As shown in Figs. 1 -4, the cross-

section of the column is circular. In additio.. ..e length of the column should be greater than the width thereof, and a ratio of length:width 6:1 or more has been found to be satisfactory . It is desirable to have the inside surfaces of the column smooth to minimize turbulence.

As shown in Figs. 1-4, the column 10 is constructed of a plurality of sections in vertical axial alignment. Upper section 11 comprises two sections 14 and 15 which are each flanged to facilitate assembly by bolts or other means not shown in the drawings.

Intermediate section 12 is compressed of a main flanged section 16 to facilitate assembly by bolts or other means not shown in the drawings, and an integral inlet leg 17, also provided at its open end with a flange.

The lower section 13 comprises a flanged main portion 18, a flanged inverted frusto-conical portion 19 and a flanged outlet portion 20 including a cylindrical section terminating in an inverted frusto-conical outlet 21. The frusto-conical outlet is attached to an elbow conduit 22 which conducts effluent from the column through valve 23 to outlet conduit 24.

Air under pressure in tank 25 is led by line 26 through valve 27 to a diffuser or bubbler 28 disposed in portion 19, by means of elbow pipe 29. As shown in Figs. 1-4, the diffuser or bubbler 28 is of approximately conical shape having its conical wall fluted vertically and provided with a plurality of small orifices. Air under pressure passes through such plurality of orifices and is delivered to the lower portion 13 of the column.

The feed slurry is pumped into the central portion 12 through inlet leg 17 by means of pump 30 from agitating conditioning tank 31. This tank has a generally cylindrical shape, terminating in a frusto-conical bottom 32. Within the tank is an impeller 33 fixed to a vertical shaft 34 which is adapted to be rotated by means (not shown) associated with a pulley 35 splined to the shaft 34. The tank is provided with a removable cover 36, to enable the ore and flotation ingredients to be added to the tank. Water, which forms the aqueous phase of the slurry, is admitted through inlet conduit 37.

Downwardly flowing aqueous medium is admitted to the upper portion 11 of the column 10 by means of valved inlet conduit 38 which

terminates in a feed tube 39 extending into the upper portion 11 of the column 10.

Foam, consisting of solid particles adhered to the rising air bubbles originating from diffuser or bubbler 28, collects in section 14 and is drawn-off through a downwardly disposed angularly extending discharge conduit 40, at the top of section 14.

Figs. 5-8 depict alternative constructions of the upper portion 11 of the column 10. In the embodiments shown in Figs. 5, 6 and 7 a means is provided in the upper zone to reduce the cross-sectional area thereof. This is for the main purpose of increasing the velocity of flow of the aqueous washing medium to enhance the contamination minimizing effect in the upper portion 11. In Fig. 5, this cross-sectional area reducing means comprises a solid tube 41 inserted in the region between the discharge conduit 40 and the inlet leg 17. In Fig. 6, the cross-sectional area reducing means is provided by forming the upper portion 11 between the discharge conduit 40 and the inlet leg 17 of a tube 15' of reduced diameter than the diameter of tube 18. In Fig. 7, the cross-sectional area reducing means is provided by a feed inlet conduit 43 extending downwardly along the longitudinal axis of the column 10 to a region corresponding to the intermediate portion 12. The conduit 43 is provided with a nozzle aperture 44. In addition, the aqueous washing medium is admitted through conduit 42 which is concentric with inlet tube 43.

The embodiment shown in Fig. 8 relates to a modified foam removal system. In that figure there is shown an enclosed box 45 having a plurality of sloping weirs 46 therein, leading to the discharge conduit 40. The foam is adapted to pass through the weirs 46 into zone 48 from which it is withdrawn through discharge conduit 40. The aqueous washing medium enters through radial inlet tube 39 and its flow is directed by rims 47 upstanding from the upper tubular section 15.

The embodiment of Figs. 9 and 10 is directed to a modified diffuser or bubbler. The bubbler or diffuser 49 is an elipsoidal

cylinder having its bottom 50 of non-porous material and provided an inlet conduit 51 for the air under pressure admitted through line 29. Its sides are also non-porous, but its eliptical cross-sectioned top 52 is provided with a plurality of 10 micron diameter orifices.

The operation will now be described with reference to Fig. 1 for an ore in which it is desired for the values to be froth flotated. Of course it is equally applicable for ores in which it is desired for the gangue and other extraneous materials to be froth flotated, leaving a residue of values.

Aqueous washing medium for example water, is passed downwardly through the column 10 from inlet conduit 38 and 39 and out through discharge line 22 and 24 through open valve 23. Air is admitted, under the required pressure to overcome the hydrostatic pressure, through lines 26 and 29 to the diffuser 28, where an upwardly directed stream of bubbles is caused to be directed through the column 10. The ore, in the form of an aqueous slurry of the desired solids content, and containing a promoter or collector which provides the valves with a water-repellant surface which will adhere to air bubbles, as well as any desired controlling or modifying agents and the required amount of frother to control air bubble size, is then pumped via pump 30 from tank 31 to inlet leg 17 and thence to the intermediate portion 12 of the column 10. The valves, having such water-repellant surface, adhere to the air bubbles and are carried upwardly to be removed at discharge conduit 40. The gangue and other extraneous material, not having such water-repellant coating are carried downwardly with the water and are discharged, along with the water, through discharge line 22 and 24.

As stated hereinbefore, if it is desired to remove the gangue and other residues as foam, such foam would be discarded, if not needed, but the values carried along with the water, will be recovered at discharge line 24.

The following Examples are given still further to illustrate the present invention.

Example 1

Amine Flotation of Quartz from Iron Ore

Procedure

Ten barrels of iron ore were received from the Iron Ore Company of Canada. This shipment, 60% of which were of a size minus 325 mesh, known as Lean Blue Ore, averaged 54 to 56% Fe, 15 to 17% SiO_2 and approximately 3% loss on ignition.

The slurry feed batch, approximately 75% solids, was conditioned with NaOH (pH 11) then with 1 lb/ton solids of dextrin and immediately after this addition, 1 lb/ton solids of primary coconut oil amine was added. The feed was pumped into a column similar to that shown in the drawings.

Half an hour after the column was operated, timed samples of underflow (from conduit 24) and overflow (from conduit 40) were taken periodically, dried, weighed and analysed. The density and flow rate of the underflow were kept constant.

One hundred and ninety six experiments were done, each experiment lasting at least 1-1/2 hour.

The following results are representative experiments carried out according to the outlined procedure.

TABLE I

	Test	Test	Test	Test	Test	Test	Test
FEED	2-1	5-1	37-1	42-1	43-1	46-1	56-2
density g/ml	2.33	2.30	2.30	2.30	2.3	2.3	1.98
solids %	75	74.5	74.5	74.5	74.5	74.5	65.0
flow rate ml/min.	146	66	-	-			
UNDERFLOW							
density g/ml	1.57	1.45	1.51	1.61	1.63	1.70	1.59
solids %	46	39.5	43.5	48	49.0	52.0	47.5
flowrate ml/min	205	202	800	800	800	800	800
OVERFLOW							
flowrate g/min	30	28.6	99.8	80.8	118.5	131	107
AIR RATE							
ml/min NTP	450	325	1600	2400	2000	1000	1800

COLUMN CHARACTERISTICS							
diameter - inch	1	1	2	2	2	2	2
upper section - feet	6	6	21	21	21	14	20
lower section - feet	3	3	6	12	12	7	7
capacity ton/inch^2 day	.36	.29	.31	.35	.38	.42	.36
RESULTS							
Underflow							
% Fe	63.5	65.0	62.7	65.9	64.3	64.1	62.0
% SiO_2	3.1	2.0	3.4	1.4	4.0	3.5	5.8
Overflow							
% Fe	11.3	23.5	12.7	10.0	11.0	12.5	8.7
% SiO_2	82.7	64.6	80.7	83.5	77.9	81.3	86.2
% Fe Recovery	96.7	91.8	96.5	98.1	96.6	96.5	97.6

These results show that the procedure of the present invention may be used to separate quartz, as the frothed overflow, from iron ore, as the underflow, with a per cent iron recovery of between 91.8 and 97.6.

Example 2

Flotation of Quartz and Dolomite from Iron Ore

Procedure

Three barrels of Cyclone Products were received from the Iron Ore Company of Canada. This shipment from Carol Lake, Labrador, averaged 27% Fe, 55% SiO_2 and 9% dolomite. The Iron oxide is mostly specularite with some magnetite.

The slurry feed batch, approximately 72% solids, was conditioned with lime, corn starch, petroleum sulphonated oil and tall oil. In the following series of experiments when the column reached equilibrium all of the underflow and overflow were collected, dried, weighed, sampled and analysed.

TABLE 2

	Test
	CP-1
FEED	
density g/ml	2.0
solids %	72
weight lb.	250

REAGENT	
lime lb/ton	0.5
Starch lb/ton	0.25
sulphonated petroleum lb/ton	0.25
Tall oil lb/ton	0.25
UNDERFLOW	
density	1.21
flowrate ml/min	795
weight lb	29.1
OVERFLOW	
weight lb	22.1
time hr	2.2
AIR RATE ml/min	6.5
COLUMN CHARACTERISTICS	
diameter inch	2
upper section feet	15
lower section feet	6
capacity ton/inch^2 day	0.089
RESULTS	
Underflow	
% Fe	43.4
% SiO_2	26.0
% dolomite	11.9
Overflow	
% Fe	4.7
% SiO_2	82.0
% dolomite	11.3
% Fe Recovery	90.4

The results in Table 2 indicate that quartz and dolomite may be flotated off from iron values in iron ore, in a column and process of the present invention, resulting in a recovery of 90.4% Fe.

Example 3

Flotation of Dolomite and Iron Ore from Quartz

Procedure

Five barrels of Fine Spiral Tailings were received from Iron Ore Company of Canada. This Shipment averaged 23% iron oxide, 66% quartz and 11.5% dolomite. The sieve analysis was as follows

+ 65 mesh	7.4 % wt
+150	24.4 "
+200	17.1 "
+325	18.0 "
-325	33.1 "

The slurry feed at approximately 70% solids was conditioned with H_2SO_4 (pH = 6.3) sulphonated petroleum oil and tall oil. All of the underflow and overflow were collected, weighed, sampled and analysed. The results were as follows:

Table 3

FEED	
weight of solids	1860 lbs
REAGENT	
H_2SO_4 (pH = 6.3)	1.3 lb/ton
sulphonated petroleum	1/2 lb/ton
tall oil	1 lb/ton
UNDERFLOW	
Time	33 hours
Flowrate typical	800 ml/min
density typical	1.28 g/ml
wt. of solids	995 lbs
AIR RATE	1050 ml/min
OVERFLOW	
wt. of solids	762 lb.
COLUMN CHARACTERISTICS	
diameter	2 inches
upper section	15 feet
lower section	6 feet
capacity	.22 ton/inch^2 day
RESULTS	
Underflow	
% Fe	1.6
% SiO_2	97.1
% dolomite	0.8
Overflow	
% Fe	35.5
% SiO_2	24.6
% dolomite	24.7
% Fe Recovery	94.3

The results in Table 3 indicate that Dolomite and iron values may be flotated from quartz in an iron ore, using the apparatus and process

The column operation was started 5 minutes after the addition of frother and half an hour was allowed for the column to reach equilibrium before sampling.

All of the overflows were collected during each experiment. The underflow rates and densities were determined at specific intervals by taking 1 liter sample which was then used for the composite underflow sample.

The total weight of the underflow was obtained using two methods:

A - density . flowrate . % solids . time

B - $\frac{\text{weight sample}}{\text{volume sample}}$. flowrate . time

The density of the underflow averaged 2.53 g/ml. Methods A and B checked within less than 1%.

The overflow and underflow were filtered, dried, sampled and analysed. The results are given below.

EXPERIMENT OP-13-1

FEED

weight of slurry	0.0964 ton
density	1.886 g/ml
solids	72.0 %
weight of solids	0.0695 ton
factor	31.5 g ton/lb

REAGENTS

lime	0.68 lb/ton	= 21.4 g
R208	0.07 "	= 2.2 g
Z6	0.01 "	= 0.3 g
tri ethyoxy butane	0.05 "	= 1.6 g
sodium sulphite	0.23 "	= 7.3 g

TEST

Time	Flowrate	Density	Air Rate
0 min.	1000 ml/min	1.119 g/ml	3.5 s.c.f.h.
10 "	980 "	1.113 "	3.5 "
20 "	990 "	1.125 "	3.5 "
30 "	990 "	1.122 "	3.5 "
40 "	1000 "	1.118 "	3.5 "
50 "	1000 "	1.128 "	3.5 "
60 "	1000 "	1.126 "	3.5 "
70 "	990 "	1.106 "	3.5 "
80 "	1010 "	1.121 "	3.5 "
90 "	1000 "	1.124 "	3.5 "
100 "	1000 "	1.120 "	3.5 "
110 "	1010 "	1.127 "	3.5 "
120 "	1030 "	1.126 "	3.5 "

duration of test	120 min
average underflow rate	1000 ml/min
average underflow density	1.122 g/min
average underflow solids	18.2 %
volume of underflow collected	13.0 liters
weight of underflow collected	2.67 Kg
total weight of underflow (calculated)	24.5 Kg
total weight of overflow collected	2.70 Kg

COLUMN CHARACTERISTICS

diameter	2 inches
lower zone	12 feet
upper zone	7 feet
capacity	0.115 ton/inch^2 day

RESULTS

weight of overflow floated	= 9.94%
underflow analysis	= 0.20% Cu
overflow analysis	= 20.4% Cu
Copper Recovery	= 91.8%

EXPERIMENT OP-13-2

FEED

weight of slurry	0.0825 ton
density	1.863 g/ml
solids	72.0 %
weight of solids	0.0593 ton
factor	36.8 g ton/lb

REAGENTS

lime	0.05 lb/ton = 1.8 g
R208	0.07 " = 2.6 g
Z6	0.01 " = 0.4 g
Sodium sulphite	0.23 " = 8.4 g
tri ethoxy butane	0.09 " = 3.3 g

TEST

Time	Flowrate	Density	Air Rate
0 min.	920 ml/min	1.166 g/ml	4.0 s.c.f.h.
15 "	938 "	1.173 "	4.0 "
25 "	935 "	1.169 "	4.0 "
35 "	940 "	1.170 "	4.0 "
45 "	950 "	1.167 "	4.0 "
55 "	945 "	1.164 "	4.0 "
65 "	940 "	1.171 "	4.0 "
75 "	948 "	1.175 "	4.0 "
85 "	950 "	1.174 "	4.0 "
95 "	950 "	1.170 "	4.0 "
105 "	950 "	1.174 "	4.0 "

duration of test	105 min
average underflow rate	942 ml/min
average underflow density	1.170 g/ml
average underflow solids	24.2 %
volume of underflow collected	11.0 liters
weight of underflow collected	not recorded
total weight of underflow (calculated)	28.0 Kg
total weight of overflow collected	3.96 Kg

COLUMN CHARACTERISTICS

diameter	2 inches
lower zone	12 feet
upper zone	7 feet
capacity	0.155 ton/inch^2 day

RESULTS

weight of overflow floated	= 12.4%
underflow analysis	= 0.09% Cu
overflow analysis	= 16.93% Cu
Copper Recovery	= 96.0%

EXPERIMENT OP-13-3

FEED	weight of slurry	0.149 ton
	density	1.928 g/ml
	solids	73.5 %
	weight of solids	0.1095 ton
	factor	49.6 g ton/lb

REAGENTS	lime	0.05 lb/ton = 2.5 g
	R208	0.07 " = 3.5 g
	Z6	0.01 " = 0.5 g
	tri ethoxy butane	0.09 " = 4.5 g

TEST	Time	Flowrate	Density	Air Rate
	0 min.	650 ml/min	1.261 g/ml	5.0 s.c.f.h.
	20 "	770 "	1.200 "	5.0 "
	40 "	825 "	1.187 "	5.0 "
	60 "	820 "	1.190 "	5.0 "
	80 "	820 "	1.208 "	5.0 "
	100 "	850 "	1.189 "	5.0 "
	120 "	815 "	1.200 "	5.0 "
	140 "	840 "	1.220 "	5.0 "
	160 "	815 "	1.199 "	5.0 "

duration of test	160 min
average underflow rate	800 ml/min
average underflow density	1.206 g/ml
average underflow solids	28.2 %
volume of underflow collected	not recorded
weight of underflow collected	30 Kg
total weight of underflow (calculated)	43.5 Kg
total weight of overflow collected	6.10 Kg

COLUMN CHARACTERISTICS

diameter	2 inches
lower zone	12 feet
upper zone	7 feet
capacity	0.156 ton/inch^2 day

RESULTS	weight of overflow floated	= 12.3%
	underflow analysis	= 0.08% Cu
	overflow analysis	= 18.35% Cu
	Copper Recovery	= 96.7%

EXPERIMENT OP-13-4

FEED

weight of slurry	0.137	ton
density	1.928	g/ml
solids	73.4	%
weight of solids	0.104	ton
factor	45.5	g ton/lb

REAGENTS

lime	0.05 lb/ton = 2.3 g
R208	0.07 " = 3.2 g
Z6	0.01 " = 0.4 g
tri ethoxy butane	0.08 " = 3.6 g

TEST

Time	Flowrate	Density	Air Rate
0 min.	995 ml/min	1.209 g/ml	4.5 s.c.f.h.
15 "	1030 "	1.191 "	4.5 "
30 "	1000 "	1.190 "	4.5 "
45 "	1025 "	1.186 "	4.5 "
60 "	1030 "	1.199 "	4.5 "
75 "	1060 "	1.202 "	4.5 "
90 "	1050 "	1.203 "	4.5 "
105 "	1080 "	1.190 "	4.5 "
120 "	1050 "	1.196 "	4.5 "
135 "	1040 "	1.202 "	4.5 "
150 "	1060 "	1.196 "	4.5 "

duration of test	150	min
average underflow rate	1040	ml/min
average underflow density	1.196	g /ml
average underflow solids	27.3	%
volume of underflow collected	11.0	liters
weight of underflow collected	3.39	Kg
total weight of underflow (calculated)	52.2	Kg
total weight of overflow calculated from the combined overflow of OP-13-4, OP-13-5 and OP-13-6 (see feed OP-13-7)	7.35	Kg

COLUMN CHARACTERISTICS

diameter	2 inches
lower zone	12 feet
upper zone	7 feet
capacity	0.198 ton/inch^2 day

RESULTS

weight of overflow floated = 12.3%
underflow analysis = 0.12% Cu
overflow analysis = 18.58% Cu
(from composite feed OP-13-7)
Copper Recovery = 95.7%

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EXPERIMENT OP-13-5

FEED

weight of slurry remaining from OP-13-4	0.0375 ton
weight of slurry	0.1425 ton
density	1.923 g/ml
solids	73.3 %
weight of solids	0.0769 ton
factor	34.4 g ton/lb

REAGENTS

lime	0.05 lb/ton = 1.7 g
R208	0.07 " = 2.4 g
Z6	0.01 " = 0.3 g
tri ethoxy butane	0.08 " = 2.7 g

TEST

Time	Flowrate	Density	Air Rate
0 min.	1050 ml/min	1.187 g/ml	4.0 s.c.f.h.
15 "	1080 "	1.166 "	4.0 "
30 "	1080 "	1.167 "	4.0 "
45 "	1040 "	1.159 "	4.0 "
60 "	1080 "	1.159 "	4.0 "
75 "	1040 "	1.162 "	4.0 "
90 "	1080 "	1.154 "	4.0 "
105 "	1100 "	1.149 "	4.0 "
120 "	1120 "	1.144 "	4.0 "
135 "	1100 "	1.152 "	4.0 "
150 "	1100 "	1.152 "	4.0 "
165 "	1080 "	1.146 "	3.5 "
180 "	1080 "	1.142 "	3.5 "

duration of test	180 min
average underflow rate	1080 ml/min
average underflow density	1.156 g/ml
average underflow solids	22.3 %
volume of underflow collected	10.0 liters
weight of underflow collected	2.56 Kg
total weight of underflow (calculated)	49.8 Kg
total weight of overflow calculated from combined overflow OP-13-4, OP-13-5 and OP-13-6 (see feed OP-13-7)	7.65 Kg

COLUMN CHARACTERISTICS

diameter	2 inches
lower zone	12 feet
upper zone	7 feet
capacity	0.161 ton/inch^2 day

RESULTS

weight of overflow floated	= 13.3%
underflow analysis	= 0.12% Cu
overflow analysis (from composite feed OP-13-7)	= 18.58% Cu
Copper Recovery	= 95.9%

EXPERIMENT OP-13-6

FEED

weight of slurry remaining from OP-13-5	0.048	ton
weight of slurry	0.155	ton
density	1.952	g/ml
solids	76.4	%
weight of solids	0.083	ton
factor	37.5	g ton/lb

REAGENTS

lime	0.05 lb/ton = 1.9 g
R208	0.07 " = 2.6 g
Z6	0.01 " = 0.4 g
tri ethoxy butane	0.08 " = 3.0 g

TEST

Time	Flowrate	Density	Air Rate
0 min.	1030 ml/min	1.182 g/ml	4.0 s.c.f.h.
15 "	940 "	1.189 "	4.0 "
30 "	975 "	1.177 "	4.0 "
45 "	1005 "	1.172 "	4.0 "
60 "	1000 "	1.177 "	4.0 "
75 "	990 "	1.181 "	4.0 "
90 "	1010 "	1.176 "	4.0 "
105 "	1015 "	1.170 "	4.0 "
120 "	1030 "	1.186 "	4.0 "
135 "	1040 "	1.172 "	4.0 "
150 "	1040 "	1.188 "	4.0 "
165 "	1005 "	1.170 "	4.0 "
180 "	1000 "	1.178 "	4.0 "
195 "	1000 "	1.170 "	4.0 "
210 "	1040 "	1.172 "	4.0 "
225 "	1020 "	1.153 "	4.0 "
240 "	1000 "	1.145 "	4.0 "

duration of test	240	min
average underflow rate	1009	ml/min
average underflow density	1.174	g/ml
average underflow solids	24.5	%
volume of underflow collected	17.0	liters
weight of underflow collected	4.72	Kg
total weight of underflow (calculated)	68.8	Kg
total weight of overflow from combined overflow OP-13-4, OP-13-5 and OP-13-6 (see feed OP-13-7)	10.5	Kg

COLUMN CHARACTERISTICS

diameter	2 inches
lower zone	12 feet
upper zone	7 feet
capacity	0.167 ton/inch^2 day

RESULTS (OP-13-6)

weight of overflow floated	=	13.3%
underflow analysis	=	0.11% Cu
overflow analysis (from composite feed OP-13-7)	=	18.58% Cu
Copper Recovery	=	96.1%

EXPERIMENT OP-13-7

FEED	weight of combined overflow slurry from Experiments OP-13-4, OP-13-5 and OP-13-6	102.0 lb
	density	1.693 g/ml
	solids	56.2 %
	weight of combined overflow	57.3 lb
REAGENTS	sodium sulphite	0.23 lb/ton ore = 22.0 g
	tri ethoxy butane	0.025 " feed = 0.3 g

TEST	Time	Flowrate	Density	Air Rate
	0 min.	230 ml/min	1.106 g/ml	0.35 s.c.f.h.
	15 "	230 "	1.117 "	0.35 "
	30 "	225 "	1.109 "	0.35 "
	45 "	222 "	1.110 "	0.35 "
	60 "	210 "	1.103 "	0.35 "
	75 "	217 "	1.095 "	0.35 "
	90 "	217 "	1.128 "	0.35 "
	105 "	218 "	1.133 "	0.35 "
	120 "	217 "	1.109 "	0.35 "
	135 "	213 "	1.134 "	0.35 "
	150 "	213 "	1.129 "	0.35 "

weight of dry overflow collected	6.23 Kg
weight of dry underflow collected	5.33 Kg
total weight	11.56 Kg

COLUMN CHARACTERISTICS

diameter	1 inch
lower zone	12 feet
upper zone	6 feet
capacity	0.621 ton/inch^2 day

RESULTS

weight of overflow floated	=	53.9%
analysis of underflow	=	6.92% Cu
analysis of overflow	=	28.5% Cu
Copper concentrate recovery	=	82.6%
Copper middling returned to circuit	=	17.1%

These results are summarized below.

TABLE 7

SUMMARY OF RESULTS

Test No.	% Cu in Conc.	% Cu in Tailings	Recovery
OP-13-1	20.4	0.20	91.8
2	16.9	0.09	96.0
3	18.4	0.08	96.7
4	18.6	0.12	95.7
5	18.6	0.12	95.9
6	18.6	0.11	96.1
7	28.5	6.92	82.6 Concentrate 17.1 Middling

The feed for Test 7 was obtained by collecting the overflow of Tests 4, 5 and 6. The underflow from this test would be returned to the grinding circuit and from there it would become part of the feed to the rougher scavenger column.

The results summarized in Table 7 indicate that the apparatus and process of the present invention can be used to flotate copper values from a copper ore. The percentage copper in the concentrate ranges from 16.9 - 20.4, the percentage copper in the tailings ranged from 0.08 to 0.20, and the recovery is from 91.8-96.7%.

These results are summarized below.

TABLE 7

SUMMARY OF RESULTS

Test No.	% Cu in Conc.	% Cu in Tailings	Recovery
OP-13-1	20.4	0.20	91.8
2	16.9	0.09	96.0
3	18.4	0.08	96.7
4	18.6	0.12	95.7
5	18.6	0.12	95.9
6	18.6	0.11	96.1
			82.6 Concentrate
7	28.5	6.92	17.1 Middling

The feed for Test 7 was obtained by collecting the overflow of Tests 4, 5 and 6. The underflow from this test would be returned to the grinding circuit and from there it would become part of the feed to the rougher scavenger column.

The results summarized in Table 7 indicate that the apparatus and process of the present invention can be used to flotate copper values from a copper ore. The percentage copper in the concentrate ranges from 16.9 - 20.4, the percentage copper in the tailings ranged from 0.08 to 0.20, and the recovery is from 91.8-96.7%.

We claim:

1. A method for the separation of one constituent from another constituent in a comminuted mixture of said constituents, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of aqueous medium within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone;

(c) establishing an aqueous slurry of said comminuted mixture and at least one conditioning agent which renders a selected said constituent hydrophobic;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at such a rate that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting one constituent as overflow at the upper region of said zone;

and (f) collecting said other constituent as underflow at the lower region of said zone.

2. A method for the separation of the values from the gangue in a comminuted mixture of ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone;

(c) establishing an aqueous slurry of said comminuted mixture and at least one conditioning agent which

renders the values in said ore hydrophobic;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at such a rate that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting said values as overflow at the upper region of said zone, said values being in the form of solid particles adhered to said bubbles;

and (f) collecting said gangue as underflow at the lower region of said zone.

3. A method for the separation of the values from the gangue in a comminuted mixture of ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone;

(c) establishing an aqueous slurry of said comminuted mixture and at least one conditioning agent which renders the gangue in said ore hydrophobic;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at such a rate that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting said gangue as overflow at the upper region of said zone, said gangue being in the form of solid particles adhered to said air bubbles,

and (f) collecting and recovering said values as underflow at the lower region of said zone.

4. The method of claims 2 or 3 wherein the rate of flow of the downwardly flowing water is correlated to the rate of flow of slurry, and

the rate of underflow to maintain a substantially constant upper level in said zone.

5. The method of claims 2 or 3 wherein the upwardly moving stream of air bubbles is produced by passing air, at a pressure of up to about 20 psig through a perforated member.

6. The method of claims 2 or 3 wherein the upwardly moving stream of air bubbles is produced by passing air, at a pressure of up to about 20 psig through a perforated member and wherein the perforated member has perforations of a size of about 5 microns to about 2500 microns.

7. The method of claims 2 or 3 wherein the upwardly moving stream of air bubbles is produced by passing air, at a pressure of up to about 20 psig through a perforated member and wherein the air bubbles have a size of about 1000 microns to about 10,000 microns.

8. The method of claims 2 or 3 wherein the aqueous slurry has a solids content of about 5-75%.

9. The method of claims 2 or 3 wherein said slurry includes a surface active agent to control the size of the air bubbles.

10. The method of claims 2 or 3 wherein the upwardly moving stream of air bubbles is produced by passing air through a perforated member, the pressure of air being defined by the formula

$$p = hd - k$$

wherein p is the pressure
h is the height of the zone
d is the average density of the contents within said zone
and k is a factor which is greater than 0 but less than 7.

11. A method for the separation of quartz from iron values in a comminuted mixture of iron ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone by passing air at a rate of 325-2400 ml/min through a perforated member;

(c) establishing an aqueous slurry of pH 11 of said iron ore, 1 lb./ton of solids of dextrin and 1 lb/ton solids contents of primary coconut oil amine, said slurry having a solids content of about 65-75%;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at a flow rate of 66-146 ml/min such that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting quartz as overflow at the upper region of said zone, said quartz being in the form of solid particles adhered to said air bubbles;

and (f) collecting and recovering said iron values as underflow at the lower region of said zone.

12. A method for the separation of quartz and dolomite from iron values in a comminuted mixture of ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone by passing air at a rate of 6.5 ml/min upwardly through a perforated member;

(c) establishing an aqueous slurry of said iron ore, 0.5 lb/ton solids of lime, 0.25 lb/ton solids of starch, 0.25 lb/ton solids of sulphonated petroleum and 0.25 lb/ton solids of tall oil, said slurry having a solids content of about 72%;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at such a rate that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting quartz and dolomite as overflow at the upper region of said zone, said quartz and dolomite being in the form of solid particles adhered to said air bubbles;

and(f) collecting and recovering said iron values as underflow at the lower region of said zone.

13. A method for the separation of dolomite and iron values from quartz in a comminuted mixture of ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone by passing air at a rate of 1050 ml/min upwardly through a perforated member;

(c) establishing an aqueous slurry of pH of 6.3 of said iron ore, about 1.3 lb/ton solids of sulphuric acid, about 0.5 lb/ton solids of sulphonated petroleum and 1 lb/ton solids of tall oil, said slurry having a solids content of about 70%;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at such a rate that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting dolomite and iron values as overflow at the upper region of said zone, said dolomite and iron values being in the form of solid particles adhered to said air bubbles;

and (f) collecting quartz as underflow at the lower region of said zone.

14. A method for the separation of molybdenum sulphide and bismuth from another gangue in a comminuted mixture of moybdite ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone by passing air at a rate of 4.0 s.c.f.m. upwardly through a perforated member;

(c) establishing an aqueous slurry of said molybdite ore, 0.1 lb/ton solids of kerosene, 0.05 lb/ton solids of pine oil, 0.05 lb/ton solids of Dowfroth, and 0.1 lb/ton potassium amyl xanthate, said slurry having a solids content of about 13%;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at a flow rate of 1360 ml/min such that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting molybdenum sulphide and bismuth as overflow at the upper region of said zone, said molybdenum sulphide and bismuth being in the form of particles adhered to said air bubbles;

and (f) collecting said gangue as underflow at the lower region of said zone.

15. A method for the separation of molybdenum sulphide from gangue in a comminuted mixture of molybdenite ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone by passing air at a rate of 4.0 s.c.f.m. upwardly through a perforated member;

(c) establishing an aqueous slurry of said ore and 0.1 lb/ton solids of kerosene, 0.05 lb/ton solids of pine oil, 0.05 lb/ton solids of Dowfroth 250, and 0.2 lb/ton solids of sodium silicate, said slurry having a solids content of about 12%;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at a rate of 1360 ml/min such that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting molybdenum sulphide as overflow at the upper region of said zone, said molybdenum sulphide being in the form of solid particles adhered to said air bubbles;

and (f) collecting said gangue as underflow at the lower region of said zone.

16. A method for the separation of copper values from gangue in a comminuted mixture of a copper ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone by passing air at a rate of 4.5-5.0 s.c.f.m. upwardly through a perforated member;

(c) establishing an aqueous slurry of said ore and 0.05-0.68 lb/ton solids of lime, 0.7 lb/ton solids of the sodium neutralized reaction product of diethyl

and s-dibutyl phosphoric acids, 0.01 lb/ton solids of potassium amyl xanthate and 0.05-0.09 lb/ton solids of triethoxy butane, said slurry having a solids content of about 56 to about 76%;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at a rate of about 650 to about 1080 ml/min such that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting said copper values as overflow at the upper region of said zone, said copper values being in the form of solid particles adhered to said air bubbles;

and (f) collecting said gangue as underflow at the lower region of said zone.

17. A method for the separation of copper values from gangue in a comminuted mixture of a copper ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone by passing air at a rate of 3.5-4.0 s.c.f.m. upwardly through a perforated member;

(c) establishing an aqueous slurry of said ore and 0.05-0.68 lb/ton solids of lime, 0.7 lb/ton solids of the sodium neutralized reaction product of diethyl and s-dibutyl phosphoric acids, 0.01 lb/ton solids of potassium amyl xanthate and 0.05-0.09 lb/ton solids of triethoxy butane and 0.23 lb/ton solids of sodium sulphite, said slurry having a solids content of about 56 to about 76% solids;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at a rate of about 920-1080 ml/min. such that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting said copper values as overflow at the upper region of said zone, said copper values being in the form of solid particles adhered to said air bubbles;

and (f) collecting said gangue as underflow at the lower region of said zone.

18. A method for the separation of copper values from gangue in a comminuted mixture of a copper ore, said method comprising:

(a) establishing and maintaining a downwardly flowing stream of water within a vertically aligned, elongated zone;

(b) establishing and maintaining an upwardly moving stream of air bubbles originating at a lower portion of said zone by passing air at a rate of 0.35 s.c.f.m. upwardly through a perforated member;

(c) establishing an aqueous slurry of said ore and 0.23 lb/ton solids of sodium sulphite and 0.025 lb/ton solids of triethoxy butane, said slurry having a solids content of about 56%;

(d) introducing said slurry into said zone at a region in said zone above said lower portion at a rate of about 210 to about 230 ml/min. such that the solids content of said slurry is greater than the solids content in said zone;

(e) collecting said copper values as overflow at the upper region of said zone, said copper values being in the form of solid particles adhered to said air bubbles;

and (f) collecting said gangue as underflow at the lower region of said zone.

19. Apparatus comprising:

(a) a vertically elongated column;

(b) means for introducing aqueous medium at the upper portion of said column;

(c) means for introducing a feed slurry to an intermediate portion of said column;

(d) means for introducing air bubbles into the lower portion of said column;

(e) means for collecting one solid constituent of said slurry from the lower portion of said column;

and (f) means for collecting another solid constituent of said slurry from the upper portion of said column, said other constituent being in the form of solid particles adhered to said air bubbles.

20. Apparatus comprising:

(a) a vertically elongated column including an upper zone, an intermediate zone and a lower zone;

(b) water inlet means extending into the upper portion of said upper zone;

(c) inlet means for introducing a feed slurry to said intermediate zone;

(d) means for introducing air bubbles into said lower zone;

(e) means for collecting one solid constituent of said slurry from the lower portion of said lower zone;

and (f) means for collecting another solid constituent of said slurry from the upper portion of said upper zone, said other constituent being in the

form of solid particles adhered to said air bubbles.

21. Apparatus comprising:

(a) a vertically elongated column including an upper zone, an intermediate zone and a lower zone;

(b) water inlet means extending into the upper portion of said upper zone;

(c) means for preparing a feed slurry;

(d) means for introducing said feed slurry to said intermediate zone;

(e) means for introducing air bubbles into said lower zone;

(f) means for collecting one solid constituent of said slurry from the lower portion of said lower zone;

and (g) means for collecting another solid constituent of said slurry from the upper portion of said upper zone, said other constituent being in the form of solid particles adhered to said air bubbles.

22. The apparatus of Claims 19, 20 or 21 wherein the cross-sectional area of said upper zone is about 1/4 to 3/4 of the cross-sectional area of said intermediate and said lower zones.

23. The apparatus of Claims 19, 20 or 21 wherein the cross-sectional area of said upper zone is about 1/4 to 3/4 of the cross-sectional area of said intermediate and said lower zones and wherein said upper zone is of reduced diameter than the diameter of said intermediate and lower zones.

24. The apparatus of Claims 19, 20 or 21 wherein the cross-sectional area of said upper zone is about 1/4 to 3/4 of the cross-sectional area of said intermediate and said lower zones and wherein said upper zone is provided with a solid member spaced from the interior walls thereof to provide such reduction in cross-sectional area.

25. The apparatus of Claims 19, 20 or 21 wherein the cross-sectional area of said upper zone is about 1/4 to 3/4 of the cross-sectional area of said intermediate and said lower zones and wherein said upper zone is provided with an axial hollow slurry inlet means extending to said intermediate zone with an aperture therein communicating with said intermediate zone, to provide such reduction in cross-sectional area.

26. The apparatus of Claims 19, 20 or 21 wherein the cross-sectional area of said upper zone is about 1/4 to 3/4 of the cross-sectional area of said intermediate and said lower zones and wherein said upper zone is provided with an axial hollow slurry inlet means extending to said intermediate zone with an aperture therein communicating with said intermediate zone, to provide such reduction in cross-sectional area and wherein said water inlet means is concentric with said axial hollow slurry inlet means.

27. The apparatus as claimed in Claims 19, 20 or 21 wherein said air bubble introducing means comprises a conical member, whose walls are fluted and perforated, said member communicated with a source of air under pressure.

28. The apparatus as claimed in Claims 19, 20 or 21 wherein said air bubble introducing means comprises a conical member, whose walls are fluted and perforated, said member communicated with a source of air under pressure and wherein said perforations are of a size of about 5 microns to about 2500 microns.

29. The apparatus as claimed in Claims 19, 20 or 21 wherein said air bubble introducing means comprises an ellipsoidal cylinder, the upper ellipsical cross-sectional portion being perforated, said cylinder communicating with a source of air under pressure.

30. The apparatus as claimed in claims 19, 20 or 21 wherein said air bubble introducing means comprises an ellipsoidal cylinder, the upper ellipsical cross-sectional portion being perforated, said cylinder communicating with a source of air under pressure and wherein said perforations are of a size of about 5 microns to about 2500 microns.

31. The apparatus as claimed in Claims 19, 20 or 21 wherein said upper collecting means includes a chamber at the top of said upper zone, an inclined weir therein and an inclined outlet cooperating with said weir.

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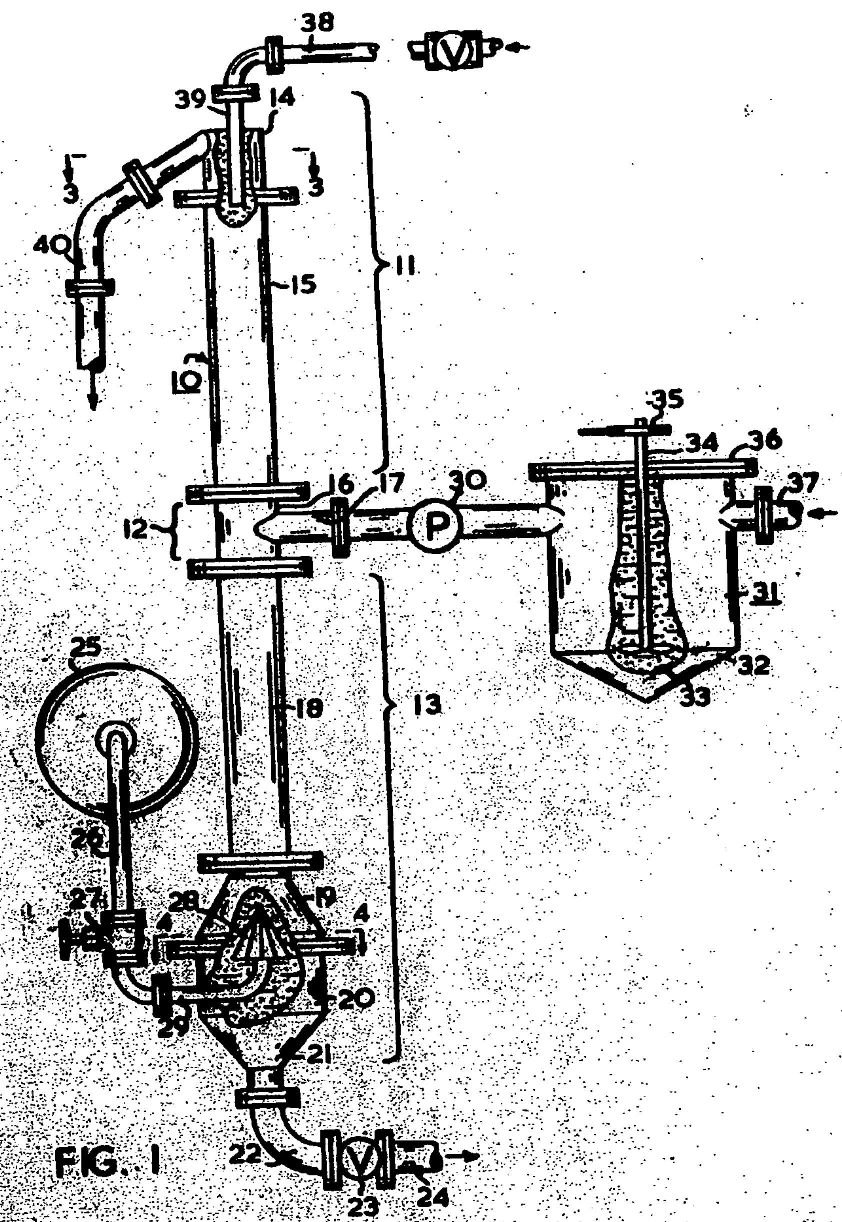

FIG. 1

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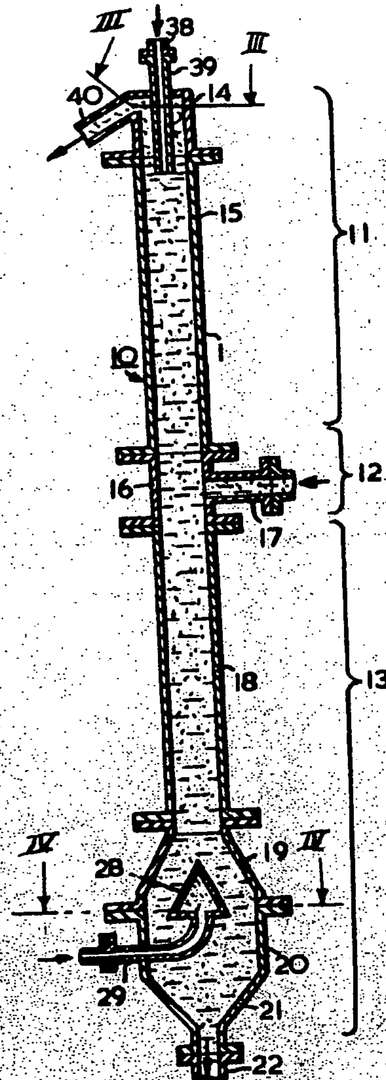

FIG. 2

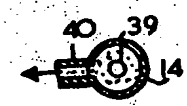

FIG. 3

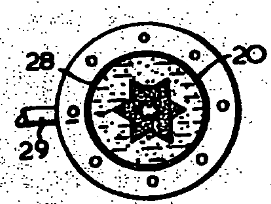

FIG. 4

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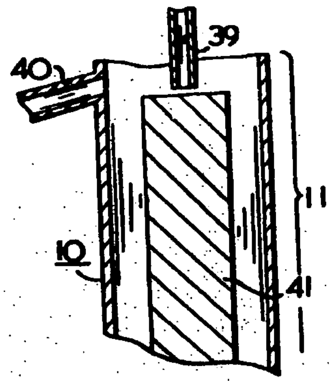

FIG. 5

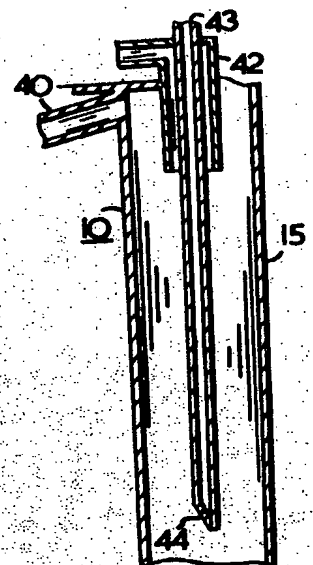

FIG. 7

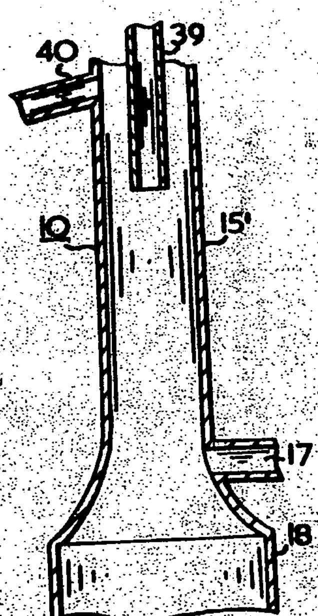

FIG. 6

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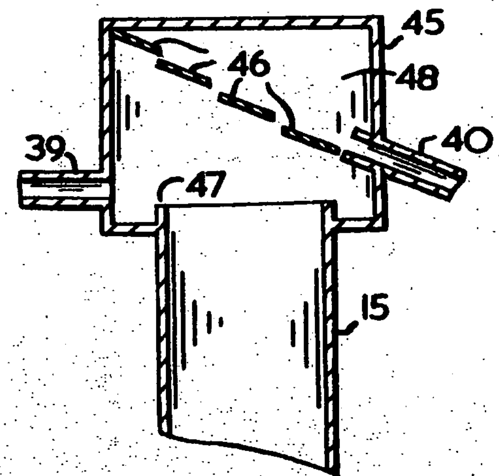

FIG. 8

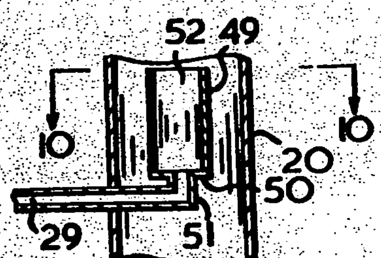

FIG. 9

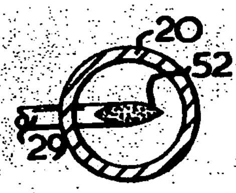

FIG. 10

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